

# A Management Model of the Northwest African Cephalopod Fishery

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## Introduction

In 1967 the Food and Agriculture Organization (FAO) of the United Nations established the Fishery Committee for the Eastern Central Atlantic (CECAF). The northwest African fishery, extending from Morocco in the north to Guinea Bissau in the south (FAO Major Fishing Area 34, Fig. 1), is within the jurisdiction of CECAF. This area is particularly rich in fish resources and is fished intensively by both foreign and local fleets (FAO, 1976).

The total annual harvest of all species in the area is about 2.5 million metric

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**ABSTRACT**—Two versions of a bioeconomic model of the northwest African cephalopod fishery, one assuming an instantaneous natural mortality rate of  $M = 1.25$  on an annual basis and the other a rate of  $M = 2.0$ , predict the harvest of octopus, *Octopus vulgaris*; cuttlefish, *Sepia spp.*; and squid, *Loligo spp.* These predictions are compared with actual harvest data, the sensitivity of model behavior to changes in important biological parameters is examined, and two management schemes for the fishery are evaluated.

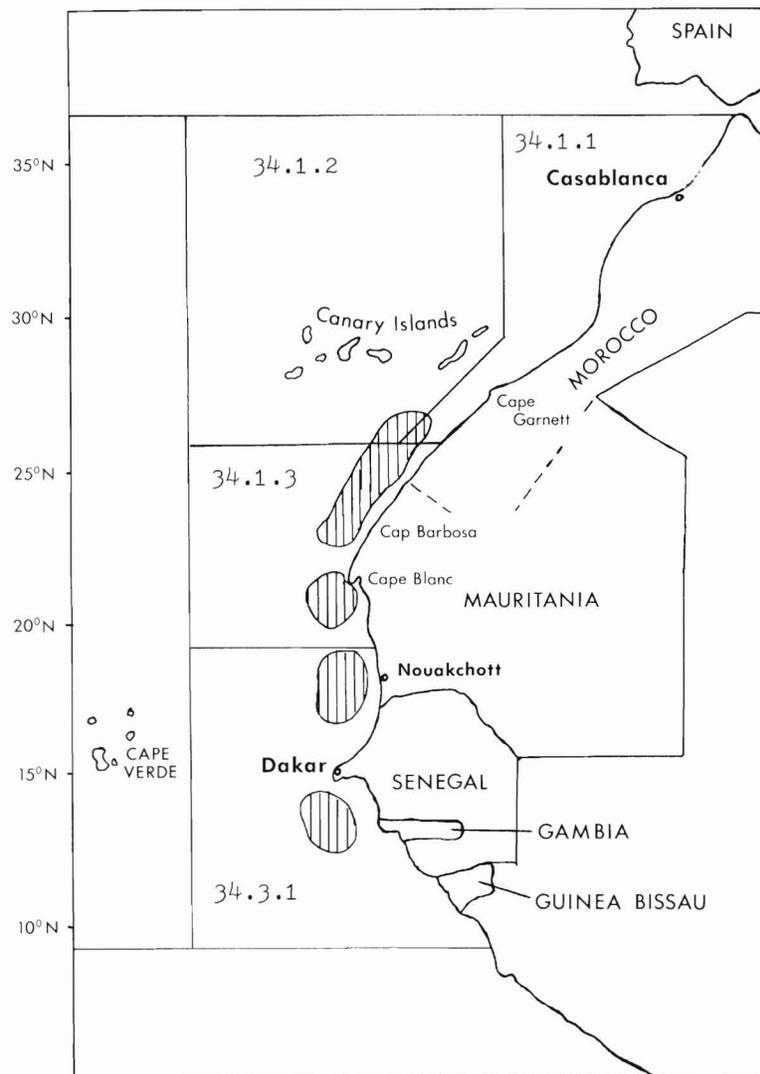


Figure 1.—FAO Major Fishing Area 34 and coastal countries of western Africa. Shaded areas represent main fishing grounds for cephalopods.

tons (t) valued at about US\$900 million<sup>1</sup>. In terms of both tonnage (about 200,000 t annually) and commercial value, the cephalopod fishery is the most important fishery in the area and also is one of the most important cephalopod fisheries in the world.

The main species harvested are octopus, *Octopus vulgaris*; cuttlefish, *Sepia officinalis officinalis*, *S. officinalis hierredda*, and *S. bertheloti*; and squid, *Loligo vulgaris* and *L. forbesi*. Fleets harvesting these species consist primarily of trawlers ranging in size from 150 to 550 gross metric tons pulling bottom trawls with mesh sizes ranging from 30 to 70 mm (FAO, 1979).

Historically, international fleets exploited the waters of northwest Africa without restriction. More recently there has been increasing control of fishing through extension of territorial waters and imposition of fishing limits by coastal countries. Of course, fish stocks are not confined within political boundaries, so fisheries management is complicated by the need to coordinate planning on a regional scale. It is anticipated that CECAF will provide the vehicle for regional planning in fisheries management for northwest Africa (Everett, 1976, 1978).

In this regard, a number of research and planning activities, including a plan to simulate mathematically the major biological and economic processes involved in the northwest African fishery, have begun (FAO, 1977). The initial effort in this undertaking involved development of a bioeconomic simulation model of the regional cephalopod fishery (Griffin et al., 1979). This paper reports on further development of the model, which focuses upon the representation of important biological aspects of the fishery, the comparison of model predictions of the harvest with actual harvest data, the examination of the sensitivity of model behavior to changes in important biological parameters, and the use of the model to evalu-

ate two management schemes for the fishery.

The ability of the model to distinguish between harvests predicted by alternate management policies also is evaluated with regard to the effects of biased estimates of important biological parameters and in view of the inherent variability of the fishery. A companion paper<sup>2</sup> discusses the economic and political implications of the management schemes to countries of the region.

### Conceptual Model of the Fishery

A simplified representation of the major biological and economic aspects of the northwest African cephalopod fishery is presented in Figure 2. The biological submodel represents the recruitment, growth, natural mortality, and harvest of octopus, *Octopus vulgaris*; cuttlefish, *Sepia* spp.; and squid, *Loligo* spp. Interactions between these species are not well known and have not been represented in the model, although the potential importance of such interactions in the management of multispecies fisheries is recognized (Gulland, 1974; May et al., 1979). Recruitment of individuals of each species into the fishery is a function of environmental factors and is treated as a driving, or external, variable. Clear evidence of a stock-recruitment relationship is lacking (FAO, 1979) and recruitment is assumed to be independent of population size. Once recruited into the fishery, individuals grow and are subjected to both natural and fishing mortality. The latter is a function of the fishing effort exerted within the fishery and is determined in the harvesting sector of the economic submodel as a function of vessel characteristics and days fished. Days fished are determined by the costs of fishing and the selling price of cephalopods. Selling price is determined by supply and demand in the marketing sector. This general approach has been used to construct man-

agement-oriented bioeconomic models of other marine fisheries (Blomo et al., 1978; Grant and Griffin, 1979).

### Simulation Model Development

Most of the relevant biological information about the northwest African cephalopod fishery has been reviewed recently (FAO, 1979) and we have relied heavily upon this information to set parameters for the simulation model. The majority of the information available pertains to octopus, although some data are available on cuttlefish. Virtually no data have been reported for squid. Economic information about the fishery has been generated from a number of published and unpublished sources as discussed elsewhere (footnote 2).

The simulation model consists of a set of nonlinear difference equations representing the dynamics of the system and has been programmed in FORTRAN for use on a digital computer. The time-step for the model is 1 month; i.e., the difference equations are solved and the state of the system is updated each month of simulated time. Input data required by the model are shown in Table 1.

The basic dynamics of the model result from changes in the number of organisms in the fishery over time:

$$N_y(t+1) = N_y(t) + \frac{\Delta N_y}{\Delta t} \quad (1)$$

Table 1.—Input data used in the simulation model.

Item	Item
1. Number of months to be simulated.	6. Parameters of von Bertalanffy growth equation and length-weight conversion equation for each species.
2. Number of species, number of cohorts per year, and number of commercial size classes of organisms.	7. Natural mortality rate and proportion of the population harvested by one real day fished.
3. Number of vessel classes, number of vessels in each class, relative fishing power of each class, and number of nominal days fished per month by vessels in each class.	8. Boundaries between commercial size classes and length of smallest organisms harvested for each species.
4. Initial number, length, and weight of organisms in model at beginning of simulation.	9. Economic data including prices of each species by size class, variable costs associated with fishing, and fixed cost of vessels by vessel class.
5. Magnitude and seasonal distribution of recruitment of organisms into fishery.	

<sup>1</sup>Christy, F. T., Jr. 1979. Economic benefits and arrangements with foreign fishing countries in the northern subregion of CECAF: A preliminary assessment. Draft report for FAO, Dakar, Senegal.

<sup>2</sup>Warren, J. P., W. L. Griffin, and W. E. Grant. Regional fish stock management: A model for northwest Africa. (In prep.)

BIOLOGICAL SUBMODEL

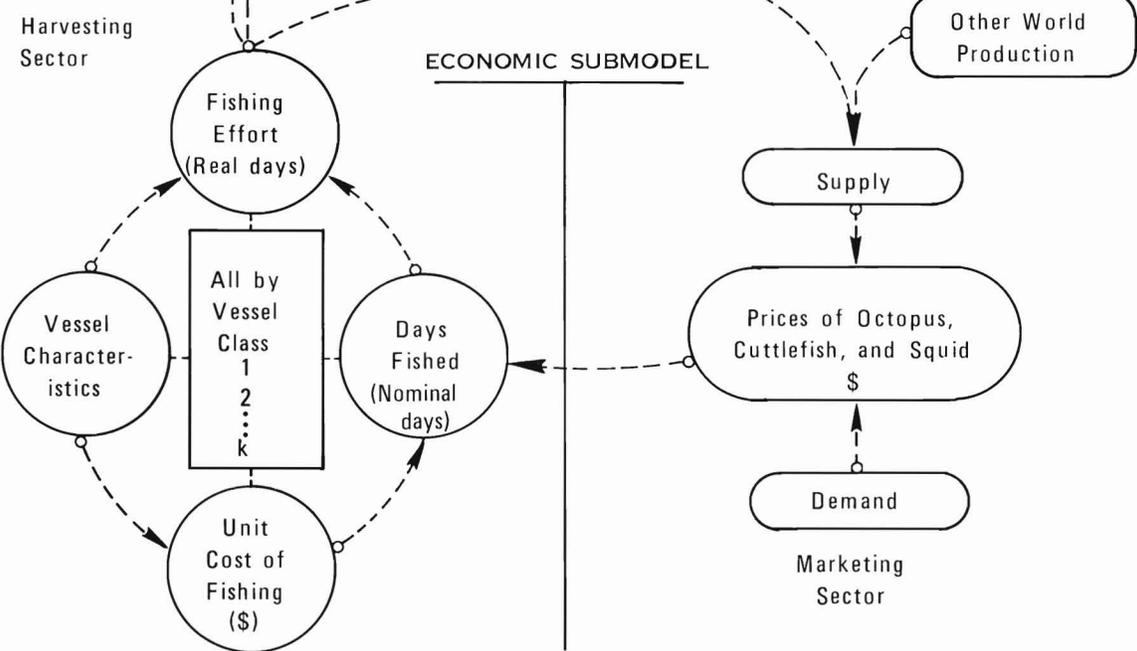
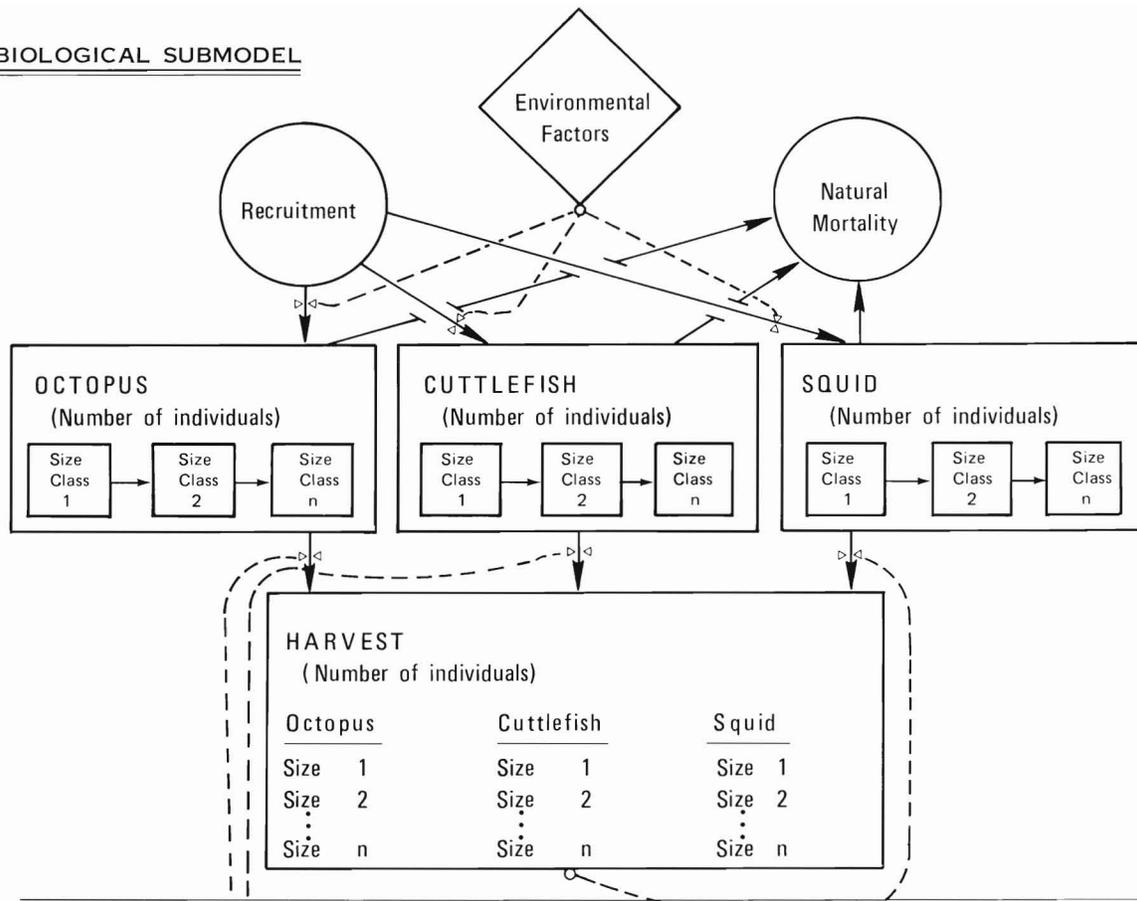


Figure 2.—Simplified representation of the major biological and economic aspects of the northwest African cephalopod fishery. Symbols follow Forrester (1961).

where  $N_{ij}(t)$  = number of organisms of the  $i$ th species,  $j$ th cohort<sup>3</sup> present at time  $t$  and

$\frac{\Delta N_{ij}}{\Delta t}$  = net change in number of organisms of the  $i$ th species,  $j$ th cohort over the time interval  $t$  to  $t+1$ .

$$\frac{\Delta N_{ij}}{\Delta t} = R_{ij} - NM_{ij} - \left( \sum_{k=1}^m FM_{ijk} \right) \quad (2)$$

where  $R_{ij}$  = number of individuals of the  $i$ th species,  $j$ th cohort recruited into the fishery during the time interval,

$NM_{ij}$  = number of individuals of the  $i$ th species,  $j$ th cohort dying due to natural (non-fishing) causes during the time interval, and

$FM_{ijk}$  = number of organisms of the  $i$ th species,  $j$ th cohort removed by fishing during the time interval by type  $k$  vessels ( $m$  = number of vessel classes)<sup>4</sup>.

Recruitment of organisms into the fishery is represented as varying on a seasonal basis:

$$R_{ij} = RMAX_i \times S_i \quad (3)$$

where  $RMAX_i$ ,

= maximum number of individuals of the  $i$ th species that can be recruited into the fishery during one time interval and

$S_i$  = a seasonality factor,  $0 \leq S_i \leq 1$ , representing the relative magnitude of recruitment of the  $i$ th species into the fishery during a given time interval;  $S_i$  values for each time in-

terval are specified as input data.

For octopus, recruitment peaks in the spring and again in the fall, whereas cuttlefish recruitment peaks in the spring (FAO, 1979). Squid recruitment is assumed to be relatively high throughout the summer. The absolute magnitude of recruitment and the specific representation of the seasonality of recruitment in the model have been determined by simulation experiments.  $RMAX_i$  and  $S_i$  have been adjusted such that 1) model behavior is consistent with available information about the dynamics of the fishery and 2) the model is a good predictor of the actual harvests of each species. Octopus are assumed to be recruited into the fishery at a mantle length of 6.43 cm, cuttlefish at 7.64 cm, and squid at 8.64 cm. These recruitment lengths are based on assumptions related to the representation of growth discussed below.

Natural mortality is represented on a species-specific basis as a constant rate per month:

$$NM_{ij} = NMORT_i \times N_{ij} \quad (4)$$

where  $NMORT_i$  = proportion of the population of the  $i$ th species dying due to natural causes during the time interval.

Although information on natural mortality is sparse, an instantaneous rate of  $M = 2.0$  on a yearly basis has been suggested for octopus in the northwest African fishery (FAO, 1979) and rates between  $M = 1.00$  and  $M = 1.50$  for squid (*Loligo pealei* and *Illex illecebrosus*) off the northeastern United States (Au, 1975). Other short-lived species (i.e., capelin, smelt, and certain minnows) also generally have  $M > 1.0$  (Beverton and Holt, 1959). Because of the uncertainty with which natural mortality rates are estimated and the importance of these rates in determining model behavior we developed two versions of the model, one using  $M = 1.25$  (0.1042 on a monthly basis) for each of the three species and one using  $M = 2.0$  (0.1667 on a monthly basis). In addition to these constant mortality rates that are applied independent of age, an upper limit on age is imposed by removing octopus and cuttlefish after they have been exposed

to the fishery for 18 months and squid after 12 months (FAO, 1979).

Fishing mortality is represented on a species-specific basis as a function of the abundance of organisms; the susceptibility of organisms to harvest, which is represented as a constant proportion of the population harvested by 1 real (standardized) day fished; and the level of fishing effort:

$$FM_{ijk} = FE_k \times HC_i \times N_{ij} \quad (5)$$

where  $FE_k$  = fishing effort in real days fished expended in the fishery during the time interval by type  $k$  vessels and

$HC_i$  = proportion of the population of the  $i$ th species removed by 1 real day fished.

Fishing effort, in turn, is calculated as the product of the relative fishing power of vessels in the fishery and the number of nominal days fished (days at sea):

$$FE_k = NDF_k \times NVES_k \times RFP_k \quad (6)$$

where  $NDF_k$  = number of nominal days fished by the "average" type  $k$  vessel during the time interval,

$NVES_k$  = number of type  $k$  vessels in the fishery during the time interval, and

$RFP_k$  = relative fishing power of type  $k$  vessels<sup>5</sup>.

Relative fishing power is calculated as the ratio of catch per day fished by a vessel in the  $k$ th vessel class to that of a standard vessel. Relative fishing power is based on 1975 landings data for all species aggregated.

In the model the susceptibility of organisms to harvest is  $1.4 \times 10^{-6}$  for all three species. This value was chosen such that the model simulated appropriately the relationship between annual catch and effort that has been observed since 1969 in the northwest African cephalopod fishery and approximated the appropriate size-class distribution in the harvest based on 1975 data from the fishery.

<sup>5</sup>Note that  $FE_k$  does not represent the fishing effort exerted by a unit operation ( $f$ ) as defined by Gulland (1969) and others.  $FE_k/NDF_k = f$  as discussed by Gulland (1969:45).

<sup>3</sup>All organisms of a given species that are introduced into the model in a given month are treated as being identical in terms of size, growth rate, mortality rate, etc., and are designated a cohort.

<sup>4</sup>Note that  $NM_{ij}$  and  $FM_{ijk}$  do not represent the natural mortality coefficient ( $M$ ) and fishing mortality coefficient ( $F$ ), respectively, as defined by Gulland (1969) and others. If the time interval  $t$  to  $t+1$  is indefinitely small, then  $NM_{ij} = MNdt$  as discussed by Gulland (1969:58).

Growth of organisms is represented on a species-specific basis by the von Bertalanffy equation:

$$l_{ij}(t) = L_{\infty ij} (1 - e^{-K_{ij}(t - t_{0ij})}) \quad (7)$$

where  $l_{ij}(t)$  = mantle length in centimeters of the  $i$ th species,  $j$ th cohort at time  $t$ ,

$L_{\infty ij}$  = asymptotic mantle length in centimeters of the  $i$ th species,  $j$ th cohort,

$K_{ij}$  = coefficient proportional to rate of catabolism based on mantle length in centimeters of the  $i$ th species,  $j$ th cohort,

$t_{ij}$  = age in years of the  $i$ th species,  $j$ th cohort, and

$t_{0ij}$  = hypothetical age in years at which mantle length of  $i$ th species,  $j$ th cohort is zero.

All organisms of a given species have the same initial size at recruitment, regardless of the time of year that they enter the fishery. Parameters of the equation for octopus in the northwest African fishery have been estimated by Guerra (FAO, 1979), however, estimates are not available for cuttlefish or squid. Initial parameter values for cuttlefish and squid were assigned based upon the assumption that the growth of these organisms was such that they entered the largest commercial size class at 20 percent of their asymptotic weight, which is the case for octopus; and upon information about their length of life, which suggests a lifespan of 2 years for octopus and cuttlefish and 1 year for squid (FAO, 1979). For squid, these initial parameter values were adjusted to increase growth rate consistent with qualitative information in FAO (1979) and with data on one of the same species (*Loligo forbesi*) off the east coast of North America (Holme, 1974). Parameter values used in the model are presented in Table 2.

The length-weight relationship used in the model to convert number of organisms in the harvest to metric tons in the harvest is of the form:

$$w_{ij} = a l_{ij}^b \quad (8)$$

where  $w_{ij}$  = weight of the  $i$ th species,  $j$ th cohort in grams,

**Table 2.**—Values of parameters of the von Bertalanffy equation ( $l = L_{\infty}(1 - e^{-K(t - t_0)})$ ) and of the length-weight conversion equation ( $w = al^b$ ) used in the simulation model. See text for symbol definitions.

Species	$L_{\infty}$	$K$	$t_0$	$a$	$b$
Octopus	40.0	0.72	0.34	0.976	2.691
Cuttlefish	45.8	0.75	0.34	0.147	2.910
Squid	40.0	1.40	0.34	0.229	2.290

$l_{ij}$  = mantle length of the  $i$ th species,  $j$ th cohort in centimeters, and

$a$  and  $b$  = parameters of the model. Length-weight relationships used were those reported for octopus and cuttlefish in the northwest African fishery by Guerra (FAO, 1979) and for squid (*Loligo forbesi*) off the east coast of North America by Holme (1974) (Table 2).

Economic considerations are linked to the biological dynamics of the fishery through fishing effort and the harvest (Fig. 2). Amount of fishing effort is determined external to the model based on historical levels of effort expended in the fishery (footnote 2) and is used as a driving variable. In the marketing sector the price of cephalopods is given for each size-class of each species. Unit costs of fishing are taken from budgets developed by size-class of vessels (footnote 2). The unit cost is defined as the sum of variable and fixed costs per vessel per month. Variable cost for a given class of vessel is calculated as the product of variable cost per day fished, number of days fished, and the number of vessels:

$$VC_k = CI_k \times NDF_k \times NVES_k \quad (9)$$

where  $VC_k$  = variable cost of a vessel of class  $k$  and

$CI_k$  = variable cost per day fished per vessel of class  $k$ .

Fixed cost for a given class of vessel is the product of the fixed cost per vessel and the number of vessels:

$$FC_k = C2_k \times NVES_k \quad (10)$$

where  $FC_k$  = fixed cost of the  $k$  class vessels and

$C2_k$  = fixed cost per vessel of class  $k$ .

Total cost for a given vessel class is the sum of the variable and fixed costs:

$$TC_k = VC_k + FC_k \quad (11)$$

Rent to the fishery obtained by a given vessel class is the difference between the total revenue and total cost:

$$RENT_k = TR_k - TC_k \quad (12)$$

where  $TR_k = \sum_{i=1}^n P_i \times TONS_{ik}$ ,

$P_i$  = price of the  $i$ th species in U.S. dollars, and

$TONS_{ik}$  = metric tons of the  $i$ th species caught by vessel class  $k$ .

### Model Validation

Validation of the model consisted of two steps. In the first step, values of parameters in each version of the model (with  $M = 1.25$  and  $M = 2.0$ ) were specified such that they represented conditions in the northwest African cephalopod fishery during 1975<sup>6</sup>. Comparison of results of 1-year baseline simulation runs under these conditions with actual 1975 harvest data (FAO, 1979) indicates that each version of the model predicts the total harvest and represents the general seasonal dynamics of the harvest of each species reasonably well. Each version predicts the general increase in landings from January through December, somewhat underestimating the actual harvest early in the year and overestimating later in the year (Fig. 3). Estimates of the annual harvest of each species and of total cephalopods are all within 7 percent of actual values, but model predictions are less accurate with regard to the size-class distributions of the harvests (Table 3). Predicted harvests of each species contain relatively too many middle-sized organisms and underestimate the proportion of both small and large organisms in the catch.

<sup>6</sup>In specifying parameter values for the two versions of the model,  $RMAX_i$  and  $S_i$  were adjusted, in the manner described earlier, independently for each version. Thus, the two versions have identical estimates for all parameters except  $NMORT_i$ ,  $RMAX_i$ , and  $S_i$ . However, the behavior of the two versions is not necessarily identical when values of  $NMORT_i$ , or any other parameter, are varied proportionally. The two versions represent two somewhat different sets of hypotheses concerning the dynamics of the fishery.

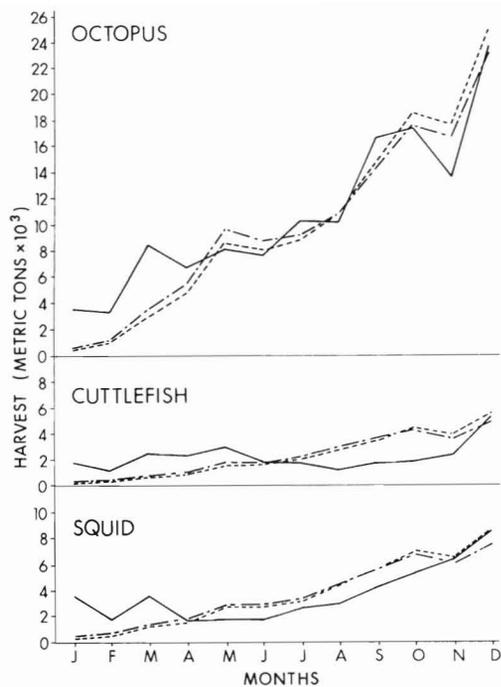


Figure 3.—Comparison of simulated ( $M = 1.25$ , dash rule;  $M = 2.0$ , dash/dot rule) and actual (solid rule, based on FAO statistics for 1975) harvests by month of octopus, cuttlefish, and squid.

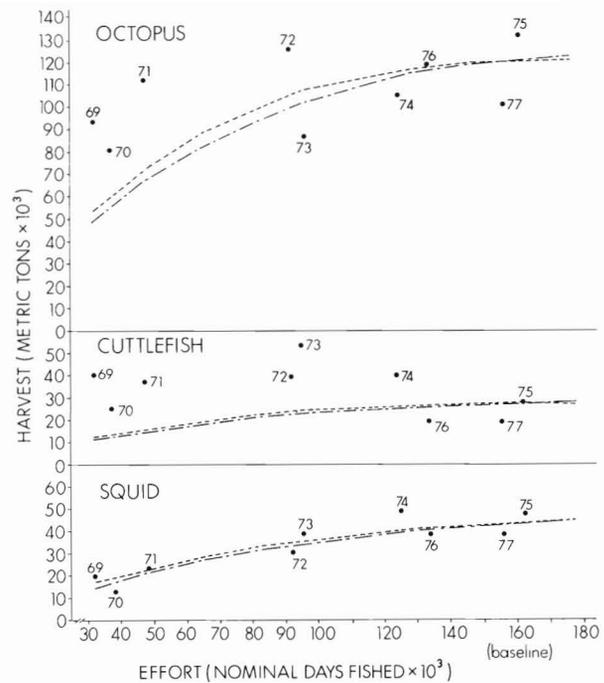


Figure 4.—Comparison of simulated ( $M = 1.25$ , dash rule;  $M = 2.0$  dash/dot rule) and actual (indicated by year based on FAO statistics for 1969 through 1977) annual harvests of octopus, cuttlefish, and squid generated by different levels of fishing effort.

Table 3.—Comparison of simulated and actual (based on FAO statistics for 1975) harvests by size class of octopus, cuttlefish, and squid. Table entries represent simulated minus actual harvest in metric tons and (percent difference).

Species	Size class	$M = 1.25$	$M = 2.0$
Total cephalopods		-10,046(-5)	-9,734(-5)
Octopus	<0.5 kg	-21,386(-47)	-14,757(-32)
	0.5-2.0 kg	17,730(33)	18,312(34)
	>2.0 kg	-5,188(-16)	-11,941(-38)
	Total	-8,845(-7)	-8,387(-6)
Cuttlefish	<0.2 kg	-1,545(-27)	-302(-5)
	0.2-0.7 kg	861(6)	1,539(12)
	>0.7 kg	-407(-4)	2,116(-23)
	Total	-1,090(-4)	-880(-3)
Squid	<0.1 kg	-3,132(-38)	-1,891(-23)
	0.1-0.4 kg	12,560(58)	12,468(57)
	>0.4 kg	-9,533(-66)	-11,037(-76)
	Total	-104(<1)	-460(-1)

In the second validation step, several additional simulations in which the level of fishing effort was adjusted from 20 to 110 percent of baseline were run and the annual harvests predicted by each version of the model at each effort level were compared with the actual annual harvests associated with similar levels of effort based on FAO historical data. Predictions of each version of the model compare favorably with actual harvests

from 1969 to 1977 (Fig. 4). One difficulty in estimating the actual effort curves results from the absence of data on the fishing effort exerted on each species. Effort figures reflect days fished for all cephalopods, while harvest data are reported by species. Thus, although vessels may be directing effort toward certain types of cephalopods, there is no basis for representing this in the analysis. For the present analysis it was assumed that effort was directed equally toward all species.

#### Sensitivity Analysis

Each version ( $M = 1.25$  and  $M = 2.0$ ) of the baseline model was subjected to a sensitivity analysis (Smith, 1970) to determine the relative influence of different parameters on model predictions of the annual harvest of each species.<sup>b</sup> Parameters for which relatively good estimates are available were increased, one

at a time, by 10 percent of their baseline values and parameters for which little information is available were increased by 100 percent. Among the parameters for which relatively good information is available, model predictions of annual harvests are most sensitive to changes in the exponent of the length to weight conversion equation ( $b$ ) (Table 4). Among the parameters for which little information is available, model predictions are most sensitive to changes in recruitment rate, but also are sensitive to changes in natural mortality rate ( $M$ ). Predicted annual harvest of each species responds similarly to most parameter changes.

#### Illustrative Use of the Model

##### Evaluation of Alternative Management Policies

To demonstrate the utility of the

<sup>a</sup>Note that fishing effort in Figure 4 is expressed as nominal days fished because estimates of real days fished are not available, except for 1975.  
<sup>b</sup>Sensitivity analysis focused on the biological parameters in the model. Economic parameters, such as the market price of cephalopods, variable costs associated with fishing, and fixed costs of vessels, were held constant during all simulations.

model within a decision-making framework, the effects of two management schemes on the harvest of cephalopods were simulated using each version of the model and compared with the baseline, or "present management," situation. Simulation of a management scheme that closes the cephalopod fishery for the period of peak recruitment during April and May, but does not alter fishing effort during the 10-month open season, indicates increased annual harvests relative to baseline for all three species (Table 5). The version of the model with  $M = 1.25$  predicts slightly larger increases than the version with  $M = 2.0$ . Harvesting efficiency in the fishery also is increased; 1.68 ( $M = 1.25$ ) or 1.61 ( $M = 2.0$ ) t being caught per 1 real day fished compared with 1.16 (both versions) under baseline conditions. The increased yield of each species results from a shift in the size-class distribution of the catch toward larger sized animals. The harvest of squid increases less than the harvests of octopus and cuttlefish due, at least in part, to the relationship between periods of peak recruitment and the period of closure. April and May are the 2 months of highest recruitment for both octopus and cuttlefish, with only 1 other month exhibiting equally high recruitment (September for octopus and June for cuttlefish). In contrast, squid recruitment is highest from May through September, and October recruitment equals April recruitment. Thus, squid are relatively less "protected" by the closure than are octopus and cuttlefish. Seasonal trends in the harvests of all three species after the April-May closure parallel the harvests during these months under the baseline situation.

Simulation of a management scheme that reduces the number of nominal days fished each month by 40 percent (achieved by limiting the number of vessels active in the fishery) indicates a decreased annual harvest relative to baseline for each species (Table 5). The version of the model with  $M = 1.25$  predicts slightly smaller decreases than the version with  $M = 2.0$ . Harvesting efficiency is increased, however, from 1.16 (both versions) to 1.56 ( $M = 1.25$ ) or 1.51 ( $M = 2.0$ ) t caught per 1 real day fished. As in the April-May closure case, the size-class distribution of the harvest

**Table 4.**—Results of sensitivity analysis indicating percent error in predicted annual harvests of octopus, cuttlefish, and squid resulting from an overestimation of either 10 or 100 percent in the indicated parameter. Relative sensitivity, indicated parenthetically, is obtained from percent error by setting the largest error in a given column equal to one.

Parameter	Percent change	$M = 1.25$			$M = 2.0$		
		Octopus	Cuttlefish	Squid	Octopus	Cuttlefish	Squid
$L$	10	29(0.29)	32(0.26)	24(0.24)	29(0.29)	32(0.27)	24(0.24)
$K$	10	23(0.23)	24(0.20)	16(0.16)	23(0.23)	25(0.21)	16(0.16)
$t_0$	10	-15(-0.15)	-15(-0.12)	-12(-0.12)	-16(-0.16)	-16(-0.13)	-14(-0.14)
$a$	10	10(0.10)	10(0.08)	10(0.10)	10(0.10)	10(0.08)	10(0.10)
$b$	10	99(1.00)	123(1.00)	97(0.98)	96(0.97)	120(1.00)	95(0.96)
Relative fishing power	10	1(0.01)	-1(-0.01)	2(0.02)	1(0.01)	1(0.01)	2(0.02)
Recruitment rate	100	98(0.99)	98(0.80)	99(1.00)	99(1.00)	98(0.82)	99(1.00)
$M$	100	-44(-0.44)	-45(-0.36)	-38(-0.38)	-58(-0.58)	61(-0.51)	-53(-0.53)
$HC$	100	14(0.14)	-18(-0.15)	2(0.02)	4(0.04)	-10(-0.08)	10(0.10)
Organisms initially in model	100	2(0.02)	2(0.02)	1(0.01)	1(0.01)	1(0.01)	1(0.01)

**Table 5.**—Comparison of harvests by size class of octopus, cuttlefish, and squid with 1) an April-May closed season and 2) a 40 percent reduction in the number of nominal days fished each month with harvest predicted under baseline conditions. Table entries represent harvest with a 1) closed season or 2) 40 percent reduction in effort minus baseline harvest in metric tons and (percent difference).

Species and size class	$M = 1.25$		$M = 2.0$	
	April-May closure	40% effort	April-May closure	40% effort
Total cephalopods	24,455(13)	-26,217(-14)	15,893(8)	33,029(-17)
Octopus <0.5 kg	-6,586(-27)	-8,846(-36)	-8,419(-27)	11,294(36)
0.5-2.0 kg	12,810(18)	-11,168(-16)	11,759(16)	11,929(-17)
>2.0 kg	12,243(46)	5,106(19)	9,078(46)	3,652(18)
Total	18,467(15)	-14,908(-12)	12,418(10)	-19,571(-16)
Cuttlefish <0.2 kg	1,113(-27)	-1,526(-37)	-1,459(-27)	-1,988(-37)
0.2-0.7 kg	1,767(12)	2,581(18)	1,730(12)	-2,794(-19)
>0.7 kg	3,353(38)	1,048(12)	2,662(37)	779(11)
Total	4,007(15)	-3,059(-11)	2,933(11)	-4,003(-15)
Squid <0.1 kg	1,064(-21)	2,065(40)	1,320(21)	2,562(40)
0.1-0.4 kg	818(2)	-7,080(-21)	326(1)	-7,481(-22)
>0.4 kg	2,227(44)	895(18)	1,536(44)	588(17)
Total	1,981(4)	-8,250(-18)	542(1)	9,455(-21)

**Table 6.**—Comparison of revenues, costs, and rents in millions of U.S. dollars obtained under 1) baseline conditions, 2) an April-May closed season, and 3) a 40 percent reduction in the number of nominal days fished each month.

Revenue, cost, and rent	$M = 1.25$			$M = 2.0$		
	Baseline	April-May closure	40% effort	Baseline	April-May closure	40% effort
Revenue	629	699	535	631	676	517
Cost	626	541	376	626	541	376
Rent	3	158	159	5	135	141

for each species is shifted toward larger sized animals, and seasonal trends in the harvests of all three species parallel baseline trends.

Comparison of economic aspects of the fishery indicates a substantial increase in rent (=revenue - costs) relative to baseline under each of the management policies (Table 6). Under the April-May closure policy, revenue is increased 11 percent ( $M = 1.25$  version) or 7 percent ( $M = 2.0$  version), and cost is reduced, because the same number of vessels are fishing fewer days per year, 14 percent (both versions). Under the 40

percent reduced effort policy, revenue is reduced 15 percent ( $M = 1.25$ ) or 18 percent ( $M = 2.0$ ), and cost is reduced, because fewer vessels are active in the fishery, 40 percent (both versions).

### Robustness of Model Predictions

The ability of each version of the model to distinguish between harvests under alternate management schemes if original estimates of important biological parameters actually are too high or too low also was evaluated. A series of simulations were run in which the point

estimates for rates of recruitment, natural mortality, and the proportion of the population harvested by 1 real day fished were adjusted, one at a time, over a relatively large range of values. When point estimates for rate of recruitment are varied from 0.2 to 2 times the baseline value, total harvests predicted by both versions of the model under the April-May closure policy remain higher, and total harvests predicted under the 40 percent reduced effort policy remain lower, than predicted baseline harvests over all test values (Fig. 5).

When natural mortality rates are varied from 0.2 to 10 times the baseline value, total harvests predicted under the 40 percent reduced effort policy remain lower than baseline over all test values, but harvests predicted under the April-May closure policy are higher than baseline for the lower test values and lower than baseline for the higher test values (Fig. 5). Harvests predicted under April-May closure and baseline policies are equal at natural mortality rates approximately 3 ( $M = 1.25$  version) or 1.8 ( $M = 2.0$  version) times higher than the rates used in the original model.

The relationship of the three policies with regard to total harvest varies as the proportion of the population harvested by 1 real day fished, which is indicative of fishing mortality rate, is varied from 0.2 to 10 times the baseline value (Fig. 5). Although the shapes of the curves relating total harvest to fishing mortality rate are similar, both versions of the model predict the largest harvest under the April-May closure policy for lower test values and under the 40 percent reduced effort policy for higher test values. Predicted harvest under the baseline policy is larger than the 40 percent reduced effort policy for lower test values, but smaller for higher test values.

#### Statistical Comparisons of Alternative Management Policies

To enable statistical comparisons of harvests under the different management policies, each version of the model was stochasticized by allowing the rates of recruitment ( $RMAX_t$ , Equation (3)) and natural mortality ( $NMORT_t$ , Equation (4)) and the proportion of each population harvested by 1 real day fished ( $HC_t$ , Equation (5)) to vary by  $\pm 50$  percent of their deterministic values each

month. This was done by generating a uniform random variable on the interval 0 to 1, adding 0.5 to the random variable, and multiplying the deterministic value of the rate to be stochasticized by the resulting number. A new random variable was generated each time a rate was stochasticized and the random number generator was seeded differently for each of the three values, recruitment, natural mortality, and proportion harvested by 1 real day fished, for each simulation. Twenty-five simulations were run representing each of the three alternatives. The 25 total cephalopod harvests predicted under each management scheme formed a set of independent, identically distributed, random variables. Results of 2-sample  $t$  tests (Snedecor and Cochran, 1967) comparing the two hypothetical management schemes with the baseline situation indicate that the total harvest of cephalopods predicted by both versions of the model is increased significantly ( $P < 0.001$ ) under the April-May closure policy and decreased significantly ( $P < 0.001$ ) under the 40 percent reduced effort policy.

#### Summary and Discussion

The current model of the northwest African cephalopod fishery, as part of the initial research and planning activities of FAO, is particularly useful in at least three ways. First, sensitivity analysis of the model identifies those parameters to which model behavior is most responsive (Table 4) and helps to identify, within a quantitative framework, the areas where data crucial to regional planning decisions are lacking. This information is useful not only in establishing future research priorities, but also in determining how much confidence should be placed in model predictions based on the confidence with which the most influential parameters have been estimated (Kowal, 1971). For the cephalopod fishery, additional data on rates of recruitment appear particularly important, although, in terms of evaluating alternate management policies, this information may be somewhat less crucial than suggested by sensitivity analysis (as discussed below). New data on rate of natural mortality and on the amount of fishing effort directed toward each species also appear critical.

Second, as a result of model validation procedures the dynamic relationship of the harvest to rates of recruitment, growth, natural mortality, and fishing mortality within the cephalopod fishery is better understood. Reliable estimates of all these rates are not available for the species under consideration here and such rates are known with confidence for very few, if any, commercially important marine stocks. Although the present model accurately predicts total harvest of cephalopods by species (Table 3) and reflects the general seasonal dynamics of the harvest (Fig. 3), one apparent shortcoming is the lack of correspondence between the size-class distributions of animals in the simulated harvests and those of animals in the actual harvests (Table 3). This discrepancy results primarily because recruitment rates cannot be adjusted relative to literature-based estimates of growth, natural mortality, and fishing mortality, such that both 1) size-class distributions are appropriate and 2) catch/effort relationships accurately represent historical catch/effort relationships over the range of effort levels for which data are available (Fig. 4). The rapid rates of growth and relatively high natural mortality rates that are suggested for cephalopods in the northwest African fishery (FAO, 1979) imply that high fishing mortality rates would be required to catch the proportions of small octopus, cuttlefish, and squid in the actual harvests. When such high fishing mortality rates are used in the model to obtain appropriate size-class distributions in the harvests, the total simulated harvests are far greater than the actual harvests. It is suggested that both natural and fishing mortality rates of cephalopods change with age (FAO, 1979) and this represents a further refinement that might be incorporated into the model as more information becomes available.

Finally, use of the model to evaluate management schemes suggests a general type of management strategy for the cephalopod fishery that warrants further consideration and also provides insight into the degree of uncertainty that must accompany current decisions regarding management alternatives. Initial comparisons of the three policies suggest that both harvesting efficiency and rent in the fishery are increased

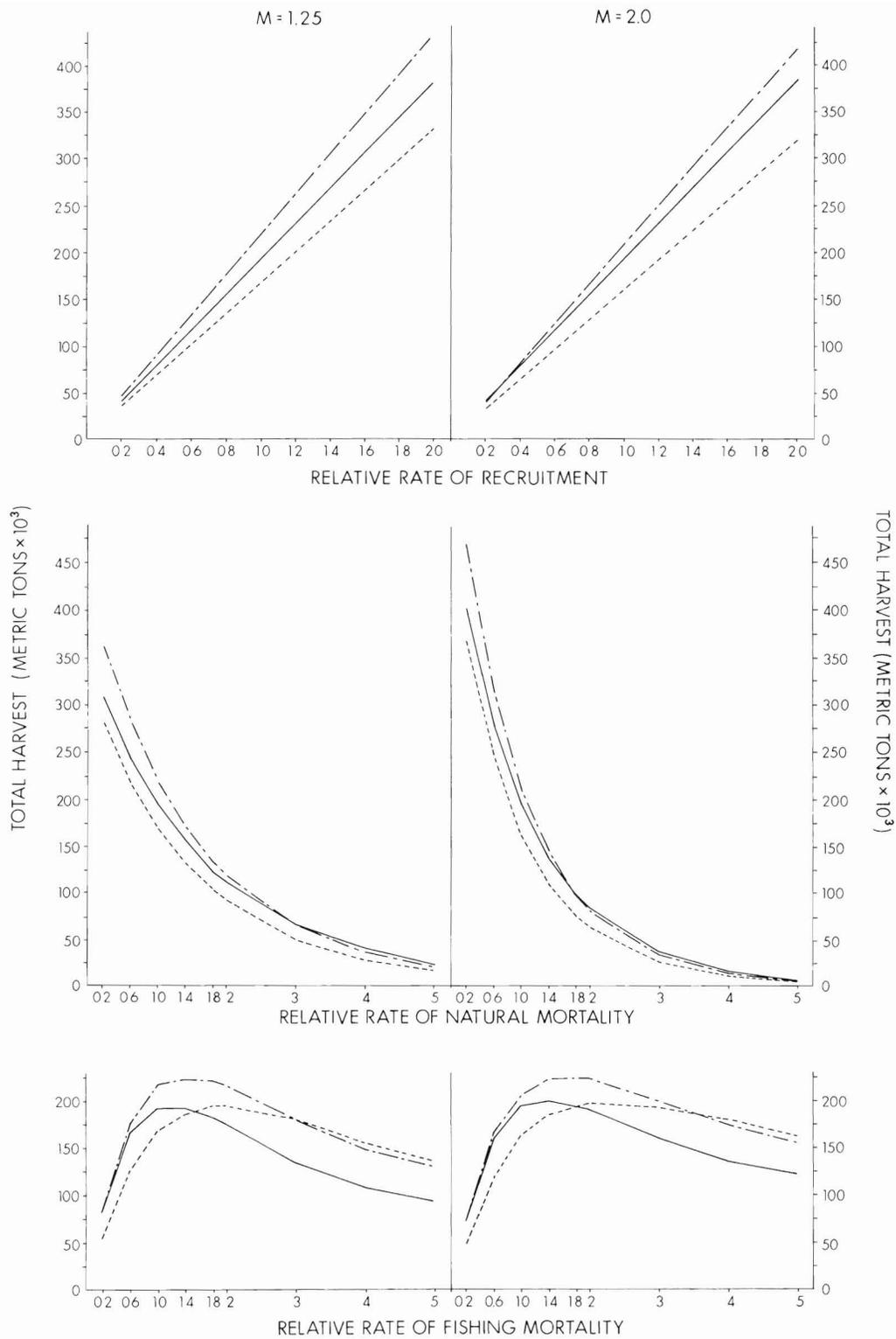


Figure 5.—Effects of changing point estimates for rates of recruitment, natural mortality, and fishing mortality on the total harvest of cephalopods predicted with 1) an April-May closed season (dash/dot rule), 2) a 40 percent reduction in the number of nominal days fished each month (dash rule), and 3) baseline conditions (solid rule). Rates are represented relative to those used in the original model.

relative to baseline by uniformly reducing fishing effort by 40 percent throughout the year or by closure of the fishery during April and May. However, 40 percent reduction of effort significantly decreases total harvest and revenue, whereas April-May closure significantly increases total harvest and revenue, relative to the baseline situation. These predictions allow for a relatively high degree of variability in rates of recruitment, natural mortality, and fishing mortality within the fishery. That is, confidence in the predictions does not depend upon correct representation of the true variability of these important variables unless we believe that they vary by more than  $\pm 50$  percent of their estimated values each month due to chance; or, more strictly, due to processes or events not represented in the model. Estimates of the variability inherent in most biological processes of importance in marine fisheries are lacking. We have assumed that  $\pm 50$  percent in any given month is a liberal estimate. Of course, the ability of the model to distinguish between alternative management policies lessens as the amount of variability represented increases.

Also of interest when interpreting model results is the question of whether outcomes of the policy comparisons are changed if estimates of important variables are, in reality, either too high or too low. In this regard, the three policies maintain the same relationship to each other concerning magnitude of total harvest over a wide range of values for recruitment rate (Fig. 5). Thus, although model behavior is sensitive to the estimate of recruitment, as indicated by sensitivity analysis (Table 4), ability to rank the policies with regard to total harvest is unaffected by the accuracy of this estimate unless the actual rate of recruitment is less than 20 percent of the original estimate. This is not the case for estimates of rates of natural or fishing mortality.

Ability to rank the 40 percent reduced effort and baseline policies with regard to total harvest is unaffected by the accuracy of the estimate of natural mortality rate if the actual rate is between 20 and 500 percent of the original estimate (Fig. 5). However, ranking of the April-

May closure and baseline policies changes if the actual rate of natural mortality is more than roughly 1.8 ( $M = 2.0$  version) or 3 ( $M = 1.25$  version) times higher than the original estimate. Likewise, ability to rank the April-May closure and baseline policies is unaffected by the accuracy of the estimate of fishing mortality rate if the actual rate is between 20 and 500 percent of the original estimate, although differences between policies become negligible as the estimates become small. But ranking of the 40 percent reduced effort and baseline policies changes if the actual rate of fishing mortality is more than roughly 1.4 ( $M = 1.25$  version) or 1.8 ( $M = 2.0$  version) times higher than the original estimate.

In conclusion, it appears that management schemes which reduce fishing effort on a seasonal basis have potential for increasing total harvest and harvesting efficiency, as well as revenue and rent, in the northwest African cephalopod fishery. To the extent that a closed season of 1.5-2 months duration can be timed to coincide with the period of peak recruitment into the fishery, increases will be maximized. Confidence in this prediction rests on assumptions that the actual recruitment rate into the fishery and the actual fishing mortality rate are both at least 20 percent of the estimated rates, that the actual natural mortality rate is less than 1.8 times the estimated rate, and that actual rates of recruitment, natural mortality, and fishing mortality do not vary due to chance by more than  $\pm 50$  percent of their estimated values each month.

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#### Literature Cited

- Au, D. 1975. Considerations on squid (*Loligo* and *Illex*) population dynamics and recommendations for rational exploitation. ICNAF Res. Doc. 75/61, 13 p.
- Beverton, R. J. H., and S. J. Holt. 1959. A review of the lifespans and mortality rates of fish in nature, and their relation to growth and other physiological characteristics. Ciba Found. Colloq. Ageing 5:142-180.
- Blomo, V., K. Stokes, W. Griffin, W. Grant, and J. Nichols. 1978. Bioeconomic modeling of the Gulf shrimp fishery: An application to Galveston Bay and adjacent offshore areas. South. J. Agric. Econ. 10:119-125.
- Everett, G. V. 1976. An overview of the state of fishery development and planning in the CECAF region. CECAF/ECAF SERIES/75/4. Food Agric. Organ., U.N., Rome, 67 p.
- \_\_\_\_\_. 1978. The northwest African fishery: Problems of management and development. CECAF/TECH. REP./78/6. Food Agric. Organ., U.N., Dakar, Senegal, 43 p.
- FAO. 1976. Report of the third session of the working party on resource evaluation of the Fishery Committee for the Eastern Central Atlantic (CECAF). FAO Fish. Rep. 183, 135 p.
- \_\_\_\_\_. 1977. Report of the fifth session of the Fishery Committee for the Eastern Central Atlantic (CECAF). FAO Fish. Rep. 195, 51 p.
- \_\_\_\_\_. 1979. Report of the ad hoc working group on the assessment of cephalopod stocks. CECAF/ECAF Series 78/11. Food Agric. Organ., U.N., Rome, 155 p.
- Forrester, J. W. 1961. Industrial dynamics. M.I.T. Press, Cambridge, Mass., 464 p.
- Grant, W. E., and W. L. Griffin. 1979. A bioeconomic model of the Gulf of Mexico shrimp fishery. Trans. Am. Fish. Soc. 108:1-13.
- Griffin, W. L., J. P. Warren, and W. E. Grant. 1979. A bioeconomic model for fish stock management: The cephalopod fishery of northwest Africa. CECAF/TECH/79/16. Food Agric. Organ., U.N., Rome, 42 p.
- Gulland, J. A. 1969. Manual of methods for fish stock assessment. Part I. Fish population analysis. Food Agric. Organ., U.N., Man. Fish. Sci. 4, 154 p.
- \_\_\_\_\_. 1974. The management of marine fisheries. Univ. Wash. Press, Seattle, 198 p.
- Holme, N. A. 1974. The biology of *Loligo forbesi* Steenstrup (Mollusca: Cephalopoda) in the Plymouth area. J. Mar. Biol. Assoc. U.K. 54:481-503.
- Kowal, N. E. 1971. A rationale for modeling dynamic ecological systems. In B. G. Patton (editor). Systems analysis and simulation in ecology. Vol. I, p. 123-194. Acad. Press, N.Y.
- May, R. M., J. R. Beddington, C. W. Clark, S. J. Holt, and R. M. Laws. 1979. Management of multispecies fisheries. Science (Wash., D.C.) 205:267-277.
- Smith, F. E. 1970. Analysis of ecosystems. In D. Reichle (editor). Analysis of temperate forest ecosystems, p. 7-18. Springer-Verlag, N.Y.
- Snedecor, G. W., and W. G. Cochran. 1967. Statistical methods. 6th ed. Iowa State Univ. Press, Ames, 593 p.